SPECIFICATION

OPTICAL TRANSMITTER MODULES

BACKGROUND OF THE INVENTION

5       The present invention relates to an optical
transmitter module and an optical communication system
employing the same, specifically to a diode laser
controlling module that has an etalon as the wavelength
filtering device to stabilize the oscillating wavelength
10   and an applied device and optical communication system
using the same.

        The optical fiber communication retains a high-speed
large capacity over a long distance and a strong resistance
against electromagnetic noises, which makes it possible to
15   organize a communication system for assuring a high
reliability.  This system has been transmitting a light
signal of one wavelength with one optical fiber.  However,
it has been requested to further expand the transmission
capacity, accompanied with the recent incoming large-
20   capacity information-oriented society.  Accordingly, the
technique on the wavelength division multiplexed optical
communication system has been put to practical use, which
transmits multiple light signals of different wavelengths
with one optical fiber, and increases the number of
25   communication channels to realize the large capacity.  With

regard to the wavelength of the light transmitted an
optical fiber, the wavelength region of a low transmission
loss in the optical fiber is used, and the 1.3 micron
waveband and the 1.5 micron waveband are called the window
of transmission.  The wavelength breadths of these windows
are limited.  Wavelength spacing between adjacent channels
has been narrowed as far as possible, whereby the number of
transmission channels has been increased.  At the present
time, the frequency spacing is 200 GHz or 100 GHz; however,
the tendency heads for 50 GHz, 25 GHz, and so forth.  To
convert them into the wavelength spacing, they are
equivalent to about 1.6 nm, 0.8 nm, 0.4 nm, 0.2 nm, and 0.1
nm, respectively, which are being narrowed.

As the wavelength spacing becomes narrower as above,
there arises a necessity to maintain the wavelengths of a
laser source precisely uniformly.  When the wavelength of a
laser source wavers and reaches a wavelength of an adjacent
channel, there appears crosstalk between adjacent channel
signals on the receiver side, which cannot assure the
reliability of information communications.  This is the
reason for the necessity.  These wavelength (or, frequency)
channels are named as the ITU-T (International
Telecommunication Union - Telecommunication Standardization
Sector) grid, which is widely recognized as the ITU
recommendation (International Telecommunication Union

Standard).

Against this backdrop, various methods have been proposed which control the wavelength of a laser source in the wavelength division multiplexed communication. For example, a newly devised method has been put forward which locks a wavelength by introducing the dielectric multi-layer film filter or the Fabry-Perot Etalon as the wavelength filtering device, and by feeding back the detected error to the operational temperature of a semiconductor laser. In particular, the etalon embraces the characteristics that transmission peaks appear repeatedly according to a multiple interference order. For this reason, it becomes possible to lock the wavelengths of plural wavelength channels with one wavelength filtering device by bringing the period of the transmission curve into coincidence with the ITU-T grid. For example, Japanese Patent Laid-open No. Hei 10-79723 discloses a method of dividing a light beam transmitted through the Etalon into two light beams, receiving both of the lights by a first and a second photo-detector, acquiring a wavelength error detection signal from a difference between both the received light signals, and locking the wavelength by using the wavelength error detection signal.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an optical transmitter module including a semiconductor laser that eliminates an influence on an etalon and so forth by ambient temperature and so forth as far as

5   possible, and stabilizes the oscillation wavelength of the semiconductor laser.

The conventional etalon has a temperature dependency. In other words, the etalon has a characteristic that the temperature variation in the materials constituting the

10  etalon varies the optical path length of the etalon, resulting from the temperature dependence of a reflective index and coefficient of linear expansion of the materials, whereby a wavelength of light transmitted through the etalon varies. Thus, the inventor has found a problem that

15  there arises a shift between the wavelength desirably locked by using the etalon and the wavelength locked in the actual laser, caused by the change in ambient temperature.

This phenomenon appears as a wavelength shift, when the so-called tracking test is performed, that is, when the

20  ambient temperature of a package incorporating a wavelength locker changes from 0°C to 70°C. Furthermore, the semiconductor laser can vary the oscillating wavelength. To vary the wavelength needs to vary the temperature of the semiconductor laser. In this case, if the etalon has a

25  temperature dependency, it will create a shift in the

locked wavelength of the semiconductor laser device, which is a problem to be solved.

In view of these facts and circumstances, the principal point of the present invention is to reduce the influence caused by the temperature dependence that the etalon holds. Furthermore, the other aspect of the invention is to reduce the number of components relating to a wavelength locking optical system, and to increase the degree of integration relating to the foregoing optical system.

The essence of a first aspect according to the present invention is as follows: the essence lies in the structural characteristic of an etalon as a wavelength error detection device. The etalon includes two sheets of plate materials such as polished glass, and a media plate for holding the two plate materials. The two plate materials are fixed to the media plate in such a manner that they are held in parallel and a specific spacing between them is held. The coefficient of thermal expansion of the media plate needs to be sufficiently low. The media plate thermally stretches depending upon the temperature of itself, and the spacing between the two plate materials varies accordingly, which leads to an error factor of the etalon as a detection device. This error factor should be as low as possible. The two plate materials and a gas (for

example, air) that fills the gap between the two plate

materials constitute the Fabry-Perot Etalon that functions

as the wavelength error detection device. According to the

embodiments of this invention, it is possible to configure

5    an optical communication apparatus, and optical

installations and systems that require sufficiently

stabilized oscillating wavelengths.

The embodiment according to the invention is

characterized in that the wavelength error detection device

10   provided with a structure different from that of the

conventional solid etalon reduces the temperature

dependence of the transmission curve of the wavelength.

The plate materials fixed to the media plate are formed

into a structure such as a cantilever or an inboard beam.

15   For example, portions near one ends of the plate materials

are fixed to the media plate, and the other portions are

made to extend outward from the media plate. Alternatively,

portions near the centers of the plate materials are fixed

to the media plate, and the other portions except for the

20   centers are made to extend outward from the media plate.

Alternatively, two media plates are prepared, and both the

ends of the plate materials are fixed to each of the media

plates. In this case, a region composed of the portions

near the centers of the plate materials is served as

25   multiple reflection regions of the laser beams.

The paired plates are made of a material that transmits the laser beams, and the surfaces, opposed to each other, of the paired plated are polished to attain a high flatness.  In addition, on the surfaces opposed to

5 each other are formed reflection membranes, whereby desired transmission curves can be obtained in accordance with the variations in the laser wavelengths.  The media plate adopts a material whose coefficient of thermal expansion is lower than the coefficient of thermal expansion $(0.5 \times 10^{-}$

10 $^{6}/°C)$ of the quartz glass that is used for the material of the conventional solid etalon.  The lower the coefficient of thermal expansion of the media plate is adopted, the better the result can be achieved.  Concretely, the coefficient of thermal expansion is selected in view of the

15 wavelength multiplicity of the optical fiber communication; that is, it is selected to such a degree that the crosstalk determined by the gaps between channels can be reduced sufficiently low.

The essence of a second aspect according to the

20 invention lies in a means that branches outgoing beams from a semiconductor laser source, by using a part of a groove on a silicon substrate that mounts at least a semiconductor laser and a condensing lens.

The laser source is mounted on a silicon substrate.

25 The silicon substrate has a tilted surface that is slant

against the optical axis of the laser beams. This tilted

surface has an inclination that reflects the laser beams in

a direction such that a reflected light from this tilted

surface intersects the optical axis of the laser beams.

5   The silicon substrate usually mounts at least the laser

source and the condensing lens as well. Part of the laser

beams that passes through the condensing lens fall on the

tilted surface. The other laser beams directly advance

without falling on the tilted surface. The laser beams are

10  split into an incident light onto the tilted surface and a

directly progressive light. The reflected light is guided

to a first photo-detector, and the progressive light is

guided to the etalon. The tilted surface on the silicon

substrate is formed by means of the anisotropic etching

15  against the crystallinity of the silicon substrate, which

is practical and highly accurate.

According to the embodiments of the invention, it is

possible to reduce the number of components of the optical

communication apparatus, and various optical installations

20  and optical systems that require the stabilization of the

oscillating wavelengths. Also, it is possible to shrink

the size of these apparatuses.


BRIEF DESCRIPTION OF THE DRAWINGS

25      Preferred embodiments of the present invention will

be described in detail based on the followings, wherein:

Fig. 1 is a structural diagram of a wavelength-controlling loop;

Fig. 2 is a diagram illustrating the relation

5   between the oscillating wavelength of a semiconductor laser and the temperature;

Fig. 3 is a sectional view illustrating the principle of operation of the etalon;

Fig. 4 is a diagram illustrating the wavelength

10   spectral characteristics of the etalon;

Fig. 5 is a plan view of an optical transmitter module that incorporates a wavelength locker;

Fig. 6 is a sectional view illustrating a configuration of a conventional optical system for locking

15   a wavelength;

Fig. 7 is a diagram illustrating the transmission characteristics with the ambient temperature varied, in the conventional optical system for locking a wavelength;

Fig. 8 is a sectional view illustrating a

20   configuration of the optical system for locking a wavelength according to the present invention;

Fig. 9 is a plan view illustrating the configuration of the optical system for locking a wavelength according to the present invention;

25   Fig. 10 is a sectional view illustrating a principal

part of the configuration of the optical system for locking
a wavelength according to the embodiment of the present
invention;

Fig. 11 is a plan view illustrating the principal

5   part of the configuration of the optical system for locking
a wavelength according to the embodiment of the present
invention;

Fig. 12 is a diagram illustrating a principal part
of another configuration of the optical system for locking

10  a wavelength according to the embodiment of the present
invention;

Fig. 13 is a diagram illustrating another
configuration of the optical system for locking a
wavelength according to the embodiment of the present

15  invention;

Fig. 14 is a diagram illustrating the principal part
of another configuration of the optical system for locking
a wavelength according to the embodiment of the present
invention;

20      Fig. 15 is a sectional view of a light interceptor
holder of the optical system for locking a wavelength
according to the embodiment of the present invention;

Fig. 16 is a plan view illustrating a configuration
of the optical system for locking a wavelength for

25  wavelength division multiplexed lights, according to the

embodiment of the present invention; and

Fig. 17 is a diagram illustrating a wavelength division multiplexed communication system to which a transmitter module according to the embodiment of the present invention is applied.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

[Description of a Basic Control Loop for Locking a Wavelength]

10 Fig. 1 illustrates a basic control loop for locking a wavelength according to the present invention. A variable wavelength laser source 100 employs a DFB (Distributed Feed Back) type, or Fabry-Perot type semiconductor laser. Or, the laser source is one in which

15 a field absorption type modulator is integrated into the DFB type semiconductor laser. Such variable wavelength laser source 100 has characteristics, as shown in Fig. 2, in which an oscillating wavelength $\lambda$ varies with an operation temperature T. Therefore, it is possible to

20 select a wavelength corresponding to an ITU-T grid by the operation temperature. Fig. 2 illustrates the relation between the temperature and the oscillating wavelength of the semiconductor laser. The horizontal axis represents the temperature, and the vertical axis the oscillating

25 wavelength. This oscillating wavelength can be brought

into correspondence with the ITU-T grid. From this

viewpoint, the vertical axis in Fig. 2 indicates the ITU-T

grid as well.

A description will be made with reference to Fig. 1.

5    In the figure, the variable wavelength laser source 100, a

condensing lens 105, a beam splitter 106, a photo-detector

110, an etalon 108, a photo-detector 109, a thermistor 403,

and so forth are mounted on a thermo-electric cooler 401.

The thermo-electric cooler 401 underlies a stem 300. This

10   will be explained with reference to Fig. 6. A drive

circuit 402 of the thermo-electric cooler 401 is able to

maintain the temperature of the laser source 100 at a

temperature corresponding to the resistance of the

thermistor 403. This controls the temperature of the

15   semiconductor laser.

On the other hand, a collimator 101 collimates the

forward outgoing beams emitted from the variable wavelength

laser source 100, and the collimated beams pass through an

optical isolator 102 and a focusing lens 103 to be coupled

20   to an optical fiber 104 for information transmission.

A temperature control loop 488 is made up, when a

switch 405 is switched to the upper side in Fig. 1. In

contrast to this, the wavelength control loop is made up,

when the switch 405 is switched from the temperature

25   control loop 488 side to a wavelength control loop 489 side.

First, the collimator 105 collimates the backward outgoing

beams from the variable wavelength laser source 100, and

the beam splitter 106 splits the collimated beams into

transmission light 107 and reflected light. The beam

5    splitter 106 is made up of laminating triangular prisms, or

if the adhesive is not preferred, it is made up with a

dielectric thin film applied to a thin plane parallel plate.

The photo-detector 110 photo-electrically transforms the

reflected light into an output monitor of the laser source

10   100. Then, the output monitor of the laser source 100 is

compared with a preset light output, and a drive circuit

404 maintains the output power of the laser source at a

constant value.

An optical system for wavelength error detection

15   according to an embodiment of the present invention is

configured as follows. That is, the transmission light 107

further advances to the etalon 108, the light that is

multiple-reflected inside the etalon 108 interferes each

other, and in consequence the transmission peak given by

20   the expression (1) is produced.

It = $1/(1 + F \sin^2(\varphi))$    $\cdots\cdots$    (1)

Where,

F = $4R/(1 - R)^2$    $\cdots\cdots$    (2)

$\varphi$ = $(2\pi nt/\lambda) \cos \theta'$    $\cdots\cdots$    (3)

25   Where, R represents the film reflection factor of each face

of the etalon 108, n the refraction factor of the etalon, t
the thickness of the etalon, $\lambda$ the wavelength of light, and
$\theta'$ the angle formed by the light inside the etalon. These
relations are illustrated in Fig. 3.

5       Here, the Snell's Law is met.

$$\sin \theta = \sin \theta' \quad \cdots\cdots \quad (4)$$

Furthermore, the repeated peak interval of the transmission
light is called the Free Spectral Range (FSR). This is
given by the following expressions (5) and (6), in the

10   wavelength domain and the frequency domain, respectively.

$$FSR = \lambda^2/2nt \quad \cdots\cdots \quad (5)$$

$$FSR = c/2nt \quad \cdots\cdots \quad (6)$$

where, c represents the velocity of light. Therefore,
Designing the thickness t, refraction factor n, film

15   reflection factor R of the etalon will bring the FSR into
coincidence with the spacing of the ITU-T grid. Bringing
the FSR into coincidence with the ITU-T grid makes it
possible to realize the wavelength error detection having
desired sharp wavelength selection characteristics over a

20   wide wavelength range. Thus, it is possible to possess
plural transmission ranges of light in a desired wavelength
that exists with specific wavelength spacing, and to bring
any of the plural transmission ranges of the light into
correspondence with the desired oscillating wavelength of

25   the laser source.

The transmission peaks arise repeatedly with variations in wavelength shift, and the spacing of the repetition is called the Free Spectral Range (FSR), as mentioned above, which is expressed by (5) or (6).

5    The photo-detector 109 in Fig. 9 receives the transmission light of the etalon thus attained, and transfers the light into a photocurrent. On the other hand, the photo-detector 110 receives the reflected light on the beam splitter 106, and transfers the light into a

10   photocurrent. The objective wavelength error detection signal is given by the following expression (7).

$$A(\lambda) = Pt - Pm \quad \cdots\cdots \quad (7)$$

Here, Pm represents the photocurrent that flows through the photo-detector 110 for monitoring the output of

15   the light power. In addition, Pt represents the photocurrent given by the foregoing expression (1). In other words, Pt signifies the photocurrent converted from the light signal by the photo-detector 109 for monitoring the wavelength placed after the etalon 108. $A(\lambda)$

20   represents a difference signal between Pt and Pm, which is an error signal.

Incidentally, as the error signal, a signal normalized by the amount of light:

$$A(\lambda) = (Pt - Pm)/(Pt + Pm) \quad \cdots\cdots \quad (8)$$

25   may be appropriately used.

Thus, the wavelength control loop carries out the feedback to the drive circuit 402 for the thermo-electric cooler 401 of the semiconductor laser 100 illustrated in Fig. 1, in such a manner that the acquired wavelength error

5    detection signal A($\lambda$) having a high sensitivity becomes zero, or a constant value. In order that the error signal given by the expression (7) or (8) captures the vicinity of one wavelength corresponding to the desired ITU-T grid, it is necessary to read the temperature of the semiconductor

10   laser in advance from the value of the thermistor 403, and to set the operation temperature to the vicinity from the relation between the temperature and the wavelength acquired according to Fig. 2. Thereafter, the switch 405 is switched into the wavelength lock loop. On the other

15   hand, an Automatic Power Control (APC) compares the output from the photo-detector 110 with a set value, and feeds back the difference obtained by the comparison to the drive circuit 404 of the laser source 100 so as to maintain the output power from the semiconductor laser at a constant

20   level. The foregoing is the basic explanation of the control loop for locking the wavelength.


[Examination on the Background of the Present Invention]

A ratio between $\varepsilon$ being a half-value breadth of the

25   transmission peak of the etalon and the FSR is called

finesse $\Phi$, which has the relation of the following expressions (9), (10), (11) with the reflection factor R of the etalon.

$$F = 4R/(1 - R)^2 \quad \cdots\cdots \quad (9)$$

5 $$\Phi = (\pi\sqrt{F})/2 \quad \cdots\cdots \quad (10)$$

$$\Phi = FSR/\varepsilon \quad \cdots\cdots \quad (11)$$

Therefore, in order to acquire a sharp spectral characteristic of the etalon, namely, a low value of $\varepsilon$, it is necessary to have a higher reflection factor on both the

10 sides of the etalon, and to generate multiple reflections repeatedly on both the sides. Accordingly, the angle of incident light to the etalon should be perpendicular or substantially perpendicular.

The foregoing is the principle of detection on the

15 wavelength error using the etalon. Fig. 5 illustrates an optical transmitter module that is configured on the basis of this principle. Fig. 5 is the plan view of the optical transmitter module.

The components of this module are contained in a

20 package 700, and necessary terminals 701 are led out. The collimator 101 condenses the light beams radiated forward from the semiconductor laser source 100, and the collimated beams advance through the optical isolator 102 to the focusing lens 103, which focuses the incoming beams to

25 couple with the optical fiber 104. On the other hand, the

collimator 105 placed on the back of the laser source 100

condenses the light beams radiated backward from the

semiconductor laser source 100, and the beam splitter 106

splits the collimated beams into two.  One of the split

5   beams reaches the photo-detector 110, which is served as

the monitor output for the light power.  The other one

passes through the etalon 108 to reach the photo-detector

109, where the wavelength detection curve as shown in Fig.

4 is obtained.  Fig. 4 illustrates the wavelength spectral

10   characteristics of the etalon.  The horizontal axis

represents the wavelength shift, and the vertical axis

represents the optical output.  FSR denotes its

representation.  These optical devices are mounted on the

stem substrate 300, and the stem substrate 300 is mounted

15   on the thermo-electric cooler 401 (Peltier effect device).

The thermo-electric cooler 401 controls the temperature of

the devices such as the semiconductor laser to a specific

level.  Thus, mainly the oscillating wavelength of the

semiconductor laser is maintained at a constant.

20        Here, the etalon 108 should also be controlled at a

constant temperature.  However, as the ambient temperature

of the package 700 varies, the temperature distribution

inside the package emerges due to conduction, radiation,

and convection of heat.  In addition, the temperature of

25   the etalon has been found to vary according to the region

thereof. For example, when the etalon is mounted on a substrate, it has been found that a temperature at a position near the mounting portion on the substrate is different from a temperature at a position remote therefrom.

5   In other words, the temperature difference has been found to emerge between the position near the mounting portion of the etalon and the upper portion therefrom. Therefore, the temperature at a position inside the etalon, through which light passes, varies with the ambient temperature of the

10   etalon. On the other hand, the etalon has temperature characteristics, and the transmission wavelength varies according to the next expression. Accordingly, the amount of variation of the transmission peak relative to the temperature variation can be estimated as follows. That is,

15   from the basic expression of the etalon in the case of the vertical incidence based on Fig. 3, the following equation can be obtained.

$2nt = m\lambda$       $\cdots\cdots$   (12)

Now, provided that a variation in optical path

20   length due to a temperature rise $\Delta T$ is given by $\delta$, and the transmission peak has been attained at a wavelength $\lambda + \Delta\lambda$, the following expression is met.

$2 (nt + \delta) = m (\lambda + \Delta\lambda)$          $\cdots\cdots$   (13)

On the other hand, by expressing the linear expansion ratio

25   as $\alpha$ ($\alpha = dt/dT$), and calculating the total differential of

the optical path length nt,

$$\delta = ((dn/dT)\ t + n\ (dt/dT))\ \Delta T$$

$$= ((dn/dT) + n\ (dt/dT))\ t\Delta T \qquad \cdots\cdots \quad (14)$$

is obtained. From the expressions (12), (13), and (14),

$$\Delta\lambda = (\lambda/n)\ ((dn/dT) + n\ (dt/dT))\ \Delta T \qquad \cdots\cdots \quad (15)$$

is obtained. That is, as shown by the expression (15), by substituting [1] for the temperature coefficient $(dn/dT)$ of the refraction factor, and [2] for the product $(n\ (dt/dT))$ of the coefficient of linear expansion and the refraction coefficient, the temperature coefficient $(\Delta\lambda/\Delta T)$ of the transmission wavelength can be expressed by the product of the sum $((dn/dT) + n\ (dt/dT))$ of [1] and [2] and $(\lambda/n)$. In addition, the temperature coefficient $(\Delta\lambda/\Delta T)$ of the transmission wavelength does not depend upon the thickness of the etalon. The refraction factor of a synthetic quartz generally used for the material of the etalon is given by the expression (16), from the linear approximation based on the values n = 1.444687 (at the wavelength 1500 nm) and n = 1.443492 (at the wavelength 1600 nm).

$$n = 1.462612 - 0.01195\lambda \qquad \cdots\cdots \quad (16)$$

Substituting the operation wavelength 1550 nm for $\lambda$ of the expression (16) will acquire n = 1.444. The temperature coefficient of the refraction factor is equal to $8.5 \times 10^{-2}$. Therefore, the temperature coefficient of the etalon in this case is as follows.

$$\Delta\lambda = 0.009 \ \Delta T \quad nm \qquad \cdots \cdots \quad (17)$$

Fig. 6 shows a conventional configuration, in which the contents of the package are illustrated in the side view. The collimator 101 collimates the backward output
5   from the laser source 100, and makes it reach the etalon 108. The photo-detector 109 receives the transmission light. These components are mounted on the stem 300, and are in contact with the thermo-electric cooler (Peltier effect device) 401.

10   When the ambient temperature of the package varies from 0°C to 70°C, which is specified as the standard environmental temperature for the optical transmitter module, a temperature at a position 199 inside the etalon through which the light passes is acquired by means of a
15   simulation. The result is that when the ambient temperature is 70°C, the temperature is 27.2°C, and when the ambient temperature is 0°C, the temperature is 23.76°C. The temperature difference generated is 3.44°C. This temperature difference is equivalent to 30.96 pm when it is
20   converted into the shift of the transmission wavelength of the etalon by the expression (17). This value 30.96 pm is equivalent to 7.7% of the grid spacing 400 pm, which does not meet the standard requirements for the lock accuracy, which is a problem. Fig. 7 illustrates the shift of the
25   wavelength; and similarly to Fig. 4, it illustrates the

wavelength spectral characteristics of the etalon in case

of the temperatures 0°C and 70°C. The horizontal axis

represents the wavelength shift, and the vertical axis

represents the optical output. To improve the shift of the

5    wavelength spectral characteristics depending on the

temperature is the technological object of the embodiment

of this invention.


[Embodiments of the Invention]

10        Prior to illustration of concrete embodiments, the

major embodiments will be enumerated.

The first embodiment of the present invention has

been described as above. That is, the construction is made

such that part of the outgoing beams from the laser source

15   are made to pass through the etalon as the first light

beams to be guided to the first photo-detection means; at

least the other part of the outgoing beams are guided to

the second photo-detection means as the second light beams

without passing through the etalon; and on the basis of the

20   differential signal of the first and second light beams

detected by the first and second photo-detection means, the

oscillating frequency of the laser source is maintained at

a specific value. And, the construction is characterized

in that the space where the etalon retains the gas is

25   served as the multiple interference regions. The

characteristic points are as follows. The media plate is combined by the two plate materials having the optical characteristics that transmit the light used in the module; the lengths of the two plate materials are set longer than

5   that of the media plate; and the space constituted by both the parts of the two plate materials being not in contact with the media plate is served as the multiple interference regions. That is, the media plate is set not to receive influence by the temperature. More concretely, the media

10  plate is made up with a solid material whose coefficient of thermal expansion is less than $10^{-7}/°C$. For example, as the solid material is preferred the one being a kind of glass, which has the coefficient of thermal expansion less than $10^{-7}/°C$. As such, the Zerodure (product name from the Shott

15  Glass Inc.), and the Pylex (product name from the Corning Inc.) are sale on the market.

        Here, the lengths of the two plate materials and the length of the media plate signify the length in the direction that intersects the optical axis of the incident

20  light on the etalon. Further usually, the two plate materials and media plate are disposed in the direction that is substantially perpendicular to the optical axis of the incident light.

        The two plates are made of the optically polished

25  glass. It is preferable in practice that the plates and

the media plate are fixed in the physical contact.

As the configurations in which the media plate is combined with the two plate materials, the following are conceivable. The first one is the so-called cantilever

5　configuration, in which the media plate is disposed only to one ends of the two plate materials, and the other ends of the two plate materials extend outward from one end of the media plate, which is the typical configuration. And, the second one is the so-called inboard beam configuration, in

10　which two media plate members constituting the media plate are disposed to both the ends of the plate materials facing to each other.

Further, the beam splitting means for transmitting part of the outgoing beams from the semiconductor laser

15　source through the etalon as the first light beams and guiding them to the first photo-detection means is a semitransparent beam splitter. The two plate materials having the transparent optical polished plane are structured in the cantilever configuration with the media

20　plate to construct the etalon. Reflection films are formed on the insides of each of the plate materials, and the outsides of each of the plate materials have anti-reflection coatings applied thereon, or take on a structure with a taper.

25　The plate on the incidence side of the plate

materials constituting the etalon can be served as a
quarter wavelength plate to control the polarization.

For example, the light beams passing through part of
the etalon and the light beams not passing the etalon are
5    obtained by splitting the incident light right and left on
a plane virtually parallel to the principal plane of the
base to retain the semiconductor laser module, or splitting
the incident light up and down on a plane virtually
perpendicular to the principal plane of the base to retain
10   the semiconductor laser module.
And, one of them is guided to the photo-detector for the
wavelength detection, and the other one is served as the
reference light.

Further, it is also possible to arrange the etalon
15   to be tilted, to split the light beams into two, to make
the first photo-detection means receive one of the two
split and make the second photo-detection means receive the
other one, and to use the difference of the photocurrents
of the photo-detection means as the wavelength error
20   detection signal.

The embodiment of the present invention includes an
arrayed light source whereby the semiconductor laser source
can emit plural wavelengths. A typical configuration is
such that, in the semiconductor laser control module, the
25   semiconductor laser is made up with plural arrayed light

sources with different wavelengths, the lights from the
plural light sources are combined to form a wave-guiding
channel, the outgoing light beams from the wave-guiding
channel are condensed by the first condensing lens, the

5   light reflected on the beam splitter is served as the
reference light, the transmitted light is split by the
second beam splitter, the reflected light is guided to the
etalon to detect a wavelength error, the transmitted light
is coupled to the optical fiber by the second condensing

10  lens. The embodiment with this configuration can be.
applied to the semiconductor laser control module, and to
other devices and systems.

Next, embodiments of the invention will be explained
concretely with reference to the drawings. Figs 8 and 9

15  show an embodiment of the invention. Fig. 8 is s side view
of a module, and Fig. 9 is a plan view thereof.

Optical components of this module are mounted on the
thermo-electric cooler 401. The variable wavelength laser
source 100 is mounted on a mount 310, and the collimator

20  101 is mounted on a silicon substrate 180 or the like. A
gas etalon as a typical example of the wavelength-selecting
device that is not likely to create shifts in wavelength
spectral characteristics depending on a temperature is made
up of members indicated by reference numerals 201, 202 and

25  203. The details of these members will be explained later.

The photo-detector 109 as a light-intercepting device is
disposed opposite to this wavelength-selecting device.
Reference numeral 106 denotes the beam splitter.  Fig. 8 is
the sectional view, and Fig. 9 is the plan view

5   corresponding to Fig. 8.  Fig. 9 also illustrates the
optical wave-guiding channel, for example, the optical
fiber 104, disposed opposite to the module shown in Fig. 8.
The optical isolator 102 is placed facing to the
semiconductor laser 101.  This serves to prevent a returned

10  light to the semiconductor laser.

Now, the gas etalon as the typical example of the
wavelength-selecting device is configured as follows.  A
solid material 201 with a very low coefficient of linear
expansion is selected as a media plate, and the media plate

15  201 is combined between plates 202 and 203 made of a
material to transmit light in an applied wavelength range,
thus forming the etalon.  Here, as seen in the plan view of
Fig. 9, the media plate 201 with a very low coefficient of
linear expansion is positioned between one ends of the

20  plates 202 and 203.  Light passes through the region where
the media plate 201 is not present.  This transmission
region and the two plate materials construct a function as
the etalon.  The media plate serves to maintain spacing
between the two plates at a specific interval.  In the

25  example of Fig. 9, the media plate 201 is disposed only

between one ends of the plates 202 and 203; however, the media plate 201 can be disposed between both the ends of the plates 202 and 203. Also, the media plate 201 can be disposed between the central portions of the plates 202 and 203. In this case, both sides of the media plate or one side thereof act as the forgoing space as a part of the etalon. Furthermore, it is necessary to select a length of the plates, by which the spacing between the plates 202 and 203 does not varies or they does not deflect in the region where the media plate 201 is not present. When the spacing varies depending on the position on the plate materials, there is a possibility that the plates cannot assure the function as the etalon. Also, when the plates deflect, the deflection is one form in which the spacing is not maintained at a specific interval, although it depends on the degree of the deflection. When the plates are retained on the media plate in a cantilever manner, it is necessary to examine the problem of deflection. When the plates are structured in an inboard beam, the problem of deflection becomes insignificant in many cases as compared to the case of the cantilever manner. For example, if the lengths of the plates are made sufficiently short, the problem of deflection can be made limited. Also, a configuration of the plate materials with a lower deflection will restrict the influence by the problem of deflection.

Now, the construction of the etalon will be described more concretely.

First, as a material for the media plate 201, the Zerodure (trade name) or the Pylex (trade name), a solid

5   material whose coefficient of thermal expansion is $10^{-7}/°C$ or less, is prepared. As a material for the plates 202 and 203, a transparent plate material such as quartz glass is selected. In addition, the material for the media plate 201 is combined between the two plate materials 202 and 203

10  to form the etalon. Here, provided that the thickness of gas appearing between the plates 202 and 203 is given by t, and the film reflection factor of the inside surfaces of the plates 202 and 203 is give by R, the aforementioned expressions (1) through (11) can be applied, so that FSR

15  and finesse can be set and the optimum wavelength detection filter can be designed. Alternatively, on the inside surfaces of the plates 202 and 203 may be formed films having a desired reflection factor R.

As a gas to fill the space, air or nitrogen gas or

20  the like may be employed. In this case, $(dn/dT) \fallingdotseq 0$ and $(dt/dT) \fallingdotseq 0$ are met; accordingly, $\Delta\lambda \fallingdotseq 0$ is deduced from the expression (15). Therefore, even if the ambient temperature varies, the shift value of a possible selected transmission wavelength can be made sufficiently low to an

25  ignorable degree. The etalon is preferably mounted in a

sealed package.  In addition, a non-reflection coating or a
tapering should be applied to the outsides of the plates
202 and 203 so as to remove the influence of ghost
reflection.  The media plate 201 is mounted only on one

5   sides of the plates 202 and 203, that is, only one media
plate is used in this case.  Accordingly, this structure
eliminates the inclinations of the plates 202 and 203,
which are created when two media plates are mounted on both
sides of the two plates.  This involves a reduction in the

10  number of components, which contributes to a cost reduction.
The mating faces of the media plate 201 and the plates 202
and 203 are optically polished so that the surface
roughness thereof becomes less than some fractions of the
wavelength of the light signal.  This makes bonding of the

15  media plate and the plates possible using the so-called
physical contact.  Or, this makes the bonding possible
using soldering, YAG welding, and Ultra-Violet adhesive
resin and so forth instead of the use of the physical
contact.

20      Fig. 10 illustrates a principal part of the
embodiment, in which the transparent material 203 is also
used as the wavelength plate.  In this case, of the plates
constituting the etalon, at least the plate placed on the
side of the semiconductor laser 100 is a quarter wavelength

25  plate.  This configuration permits polarization control by

the plate.  This will reduce undesired resonance generated
in the optical system.

More specifically, a resonator 262 is formed between
the end face of the semiconductor laser 100 and the inside
5    of the transparent plate 202, or a resonator 261 is formed
between the end face of the semiconductor laser 100 and the
inside of the transparent plate 203.  Accordingly, if the
oscillating wavelength of the semiconductor laser varies,
ripples will be created on the photocurrent of the photo-
10   detector 110, which is a problem.  This phenomenon results
from the mutual interference of light reflected from each
of the faces.

For this reason, the plate 202 is formed into a
quarter wavelength plate, and the linearly polarized light
15   from the semiconductor laser 100 is made to pass through
the quarter wavelength plate, which is transformed into
circularly polarized light.  In addition, the reflected
light on the plate 203 again passes through the plate 202,
which is transformed into the perpendicularly polarized
20   light from the original linearly polarized light.  Thus,
the polarizations of both are perpendicular; the
interferences will not be created accordingly, and the
optical output power is maintained at a substantially
constant level, thereby reducing the foregoing ripples.

25       Fig. 11 illustrates a configuration of the gas

etalon made up of the media plate 201 and the plates 202
and 203 according to the embodiment of the present
invention, in which the etalon is used as the wavelength
error detection filter for locking the wavelength. Fig. 11

5   illustrates a plane configuration of the major part. That
is, the light beams from the semiconductor laser 100 are
collimated by the condensing lend 101. This ray bundle is
laterally divided into two parts ideologically. One of the
parts of the ray bundle is directed to reach a photo-

10  detector 204 that gives the photocurrent signal Pm in the
aforementioned expressions (7) and (8). The other passes
through the gas etalon to reach a photo-detector 205 that
gives the photocurrent signal Pt to originate the
wavelength error detection signal $A(\lambda)$. The operation

15  after attaining the wavelength error detection signal $A(\lambda)$
is the same as the aforementioned. This embodiment permits
the optical system illustrated in Fig. 11 to attain a
signal for the wavelength error detection.

Fig. 12 illustrates another configuration of the gas

20  etalon made up of the media plate 201 and the plates 202
and 203, in which the etalon is used as the wavelength
error detection filter for locking the wavelength. Fig.
12A is a plan view of the major part of this embodiment,
and Fig. 12B is a sectional view thereof. In the figures,

25  the same portions as in the foregoing embodiment are given

the same reference numerals. The collimated light beams

from the condensing lens 101 are longitudinally split into

two parts ideologically. One of the parts of the ray

bundle is directed to reach the photo-detector 204 that

5　gives the photocurrent signal Pm in the expressions (7) and

(8). The other one of the light beams passes through the

gas etalon to reach the photo-detector 205 that gives the

photocurrent signal Pt to originate the wavelength error

detection signal A($\lambda$). In the embodiment of Fig. 11, the

10　light beams are split on a plane parallel to the substrate;

however in this embodiment, the light beams are

longitudinally split on a plane perpendicular to the

substrate. It is essential to dispose the laser, etalon,

photo-detectors, and so forth, in such a manner that part

15　of the ray bundle passes through the etalon, and at least

part of the remaining ray bundle does not pass through the

etalon.

　　　　Fig. 13 illustrates another embodiment of the

present invention. In this embodiment, the gas etalon is

20　arranged slant to the optical axis of the laser beams.

Fig. 13A is a plan view of the major part of this example,

and Fig. 13B is a sectional view thereof. In the figures,

the same portions as in the foregoing embodiments are given

the same reference numerals.

25　　　　A lens 101 condenses divergent light beams from the

semiconductor laser 100 into slightly divergent light beams
177. In addition, the gas etalon (201, 202 and 203)
according to the invention is laid out slightly tilted to
the central optical axis of the beams 177. Thus, the beams
5    that reach the two photo-detectors arranged adjacently
laterally are made to each pass through the etalon with
different optical path lengths. With this configuration,
the wavelength response of the two photo-detectors 204 and
205 are slightly shifted on the wavelength axis as shown in
10   Fig. 4. Therefore, to obtain the difference of the outputs
from the two photo-detectors 204, 205 will attain the
wavelength error signal. In this type of wavelength error
detection optical system, the temperature dependence of the
gas etalon that functions as the wavelength error detection
15   filter is almost ignorable; therefore, if the ambient
temperature of the whole package varies, the influence will
be reduced.

Fig. 14 illustrates a wavelength locking optical
system according to another embodiment of the present
20   invention. This embodiment provides a configuration to
attain more easily the light for acquiring the photocurrent
Pm. That is, a reflection mirror is attached to a portion
of the retaining substrate for introducing the light to the
etalon, thereby reducing the number of the components or
25   saving the space. The retaining substrate with such a

reflection mirror is formed with a silicon substrate. A

mirror surface tilted to the light beams can be formed

precisely and easily by the so-called anisotropic etching

utilizing the anisotropy of the crystal lattice of the

5    silicon. Fig. 14A is a plan view of this embodiment, and

Fig. 14B is a side view thereof.

       The condensing lens 101 condenses the light beams

from the semiconductor laser 100 into collimated beams,

which are directed to the gas etalon made up of the media

10   plate 201 and the plates 202 and 203. In this embodiment,

both the semiconductor laser 100 and the condensing lens

101 are mounted on a silicon substrate 206. This silicon

substrate 206 has a V-shaped groove thereon formed by the

anisotropic etching. The etching is performed to make the

15   bottom of the V-shaped groove into a plane. More precisely,

the sectional shape of this groove is not V-shaped. As

shown in Fig. 14, the sectional shape has two facing sides

and a plane connecting the two sides. The condensing lens

101 is mounted on the bottom of this V-shaped groove. One

20   of the tilted surfaces of the V-shaped groove is served as

the reflection mirror. The semiconductor laser 100 is

mounted on the top of a hill-shaped region of the silicon

substrate 206. A reflection mirror 207 formed on the

substrate 206 reflects part of the light beams condensed by

25   the condensing lens 101. This reflection will divide the

light beams condensed by the condensing lens 101. The

photo-detector 110 photo-electrically transforms the

reflected light into the photocurrent Pm. The light

passing through without being reflected will pass through

5   the gas etalon to reach the photo-detector 109. The photo-

detector 109 photo-electrically transforms this light into

the photocurrent Pt.

With the silicon substrate thus devised, the beam

splitter 106 illustrated in Fig. 1 becomes unnecessary,

10  which makes it possible to realize not only reducing the

number of components, but also enhancing the integration by

the space saving. Furthermore, the light source and the

condensing lens are mounted on the same silicon substrate;

accordingly, the module becomes insensitive to the impact

15  of thermal expansion with the temperature variation.

Therefore, the position of the condensing lens relative to

the light source does not substantially changes, and the

variations in the incident angle on the etalon can be

reduced accordingly. Another condensing lens 208 condenses

20  the light beams radiated on the front of the semiconductor

laser 100 into parallel or convergent light beams. In the

case of parallel light beams, another condensing lens 209

of a ball lens or the like couples the beams to an optical

fiber 210. Between the condensing lens 208 and the other

25  condensing lens 209 are arranged a sealing window 211 and

an optical isolator 212. Fig. 15 is a sectional view of a
holder 301 for the photo-detector 110 that receives the
light beams reflected upward by the silicon mirror. The
section intersects the optical axis of the condensing lens.

5　　The holder 301 is mounted on the stem 300. The holder 301
is formed in a shape of a bridge to straddle the silicon
substrate 206 that mounts the semiconductor laser 100 and
the condensing lens 101 and so forth, thereby adjusting the
height.

10　　　　　Furthermore, the mounting of the semiconductor laser
on a substrate separate from the silicon substrate, for
example, a Covar substrate makes it possible to take
countermeasures against radio frequency noises. In this
case, naturally the condensing lens 208 and the photo-

15　detector 110 can be mounted on the silicon substrate, and
the foregoing reflection mirror can be applied to the
silicon substrate.

　　　　　Fig. 16 illustrates a configuration wherein the
light radiated on the front of the semiconductor laser 100

20　is used for the wavelength error detection signal.
Furthermore, this embodiment employs multi-channel light
sources.

　　　　　An optical wave-guide 952 guides each of the light
power outputs from a semiconductor laser array 951 wherein

25　semiconductor laser devices each having different

oscillating wavelengths are arrayed in a line to a
wavelength multiplexer 953 that multiplexes the different
wavelengths and outputs the multiplexed output to a single
mode wave-guide.  Then, an optical amplifier 954 amplifies

5    the multiplexed light, which is guided to an optical
modulator 955.  The condensing lens 208 condenses the light
beams outputted from the optical modulator 955, which are
guided to the beam splitter 213 by way of the optical
isolator 212.  The photo-detector 110 receives the light

10   beams reflected on the beam splitter 213, and produces the
photocurrent Pm.  In replacement of the beam splitter 213,
the silicon mirror 207 of this invention can be formed on
the front for use.  On the other hand, the light beams
passing the beam splitter 213 are split into two by a

15   second beam splitter 214.  The reflected light beams here
pass through the gas etalon (media plate 201, plates 202
and 203), and reach the photo-detector 109.  Then, the
photo-detector 109 photo-electrically transforms the light
beams into the photocurrent Pt.  The light beams passing

20   through the second beam splitter 214 passes through the
second condensing lens 209, and reach the optical fiber 210.

Fig. 17 illustrates a configuration of another
embodiment according to the invention, namely, a basic
configuration for implementing a wavelength division

25   multiplexed communication.

Optical transmitter modules 310 according to the invention are prepared each for the channels of the ITU-T grid wavelengths, and a great number of them are arrayed in multiple. These lights are joined to a wavelength

5   multiplexer 320, and joined light passes through one optical fiber 330. The light signal transmitted in this state is multiplexed in terms of the wavelength. Each of the wavelength division multiplexed lights carries a signal, and is transmitted the optical fiber over a long distance.

10   When the light signal transmits about 600 km, for example, the light signal attenuates due to the loss of the optical fiber. Accordingly, a repeater 340 with an optical fiber amplifier becomes necessary. As the optical fiber amplifier, an EDFA (Erbium Doped Fiber Amplifier), for

15   example, is widespread, which collectively amplifies the channel signals in the so-called c-band.

In this band, the wavelength is about 32 nm. In case of the wavelength spacing being 0.8 nm, the band can accommodate 40 channels, and in case of 0.4 nm, the band

20   can accommodate 80 channels. A demultiplexer 350 demultiplexes the light signals passing through several repeaters each for the spectral wavelengths, which are converted into electric signals each for the channels by receiver modules 360. In such a large capacity wavelength

25   division multiplexed communication, the stabilized

wavelength locking mechanism having been described in detail so far fulfils an important role with regard to the light source, in order to remove the crosstalk between the channels.

5          As the aspects of the invention have been descried, the construction composed of the basic components permits optically electrically stabilized wavelength locking against the variations of ambient temperature of the etalon, and the performance of the etalon can be utilized at its

10    maximum.  That is, from the viewpoints of resolution of wavelength selection, coefficient of utilization of light, enhancement of packaging density of the etalon inside the laser source module, mechanical stability of the etalon, compensation of locked wavelength shift against temperature

15    variation of the etalon, and so forth, it is possible to solve the technical subjects that have been impossible to solve so far, especially the problem of locked wavelength shift of the etalon by the temperature variation.  Moreover, to utilize the wavelength control system according to the

20    invention will lock the oscillating wavelength of a semiconductor laser with a higher accuracy than the conventional.  Furthermore, to vary the temperature of a semiconductor laser will make it possible to shift the oscillating wavelength of a semiconductor laser to an

25    arbitrary ITU-TS grid, and to lock the wavelength at the

same time.  Furthermore, the embodiment according to the
invention will provide a laser source essential to the
wavelength division multiplexed communication apparatus, or
the router for wavelength channels.

5          According to the embodiment of the invention, since
the temperature dependence of a wavelength error detection
device can be ignored, even if there is a temperature
variation in the wavelength locking optical system, it is
possible to reduce the shift from the target locking range
10   of a wavelength locker.

According to the embodiment of the invention, it is
possible to reduce the influences of the ambient
temperature, etc., as much as possible, and to provide a
semiconductor laser control module with the oscillating
15   wavelength stabilized.  Furthermore, the embodiment of the
invention will provide an applied system, optical system,
using the semiconductor laser control module that has the
influences of the ambient temperature, etc., reduced as
much as possible and the oscillating wavelength stabilized.

20          According to the embodiment of the invention, the
wavelength of a semiconductor laser can be stabilized.